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MEDICAL SURVEY OF RONGELAP PEOPLE, MARCH 1958, FOUR YEARS AFTER EXPOSURE TO FALLOUT

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Background

This report presents the results of a medical survey carried out in March 1958 on the Marshallese people of Rongelap Atoll who were accidentally exposed to radioactive fallout in March 1954. The accident occurred following the detonation of a high yield thermonuclear device during experiments at Bikini in the Pacific Proving Grounds. An unpredicted shift in winds caused a deposition of significant amounts of fallout on four inhabited Marshall Islands nearby and on 23 Japanese fishermen aboard their fishing vessel, the Lucky Dragon (see Figure 1.) Sixty-four inhabitants of the island of Rongelap, 105 nautical miles away from the detonation, received the largest fallout exposure: an estimated dose of 175 r whole-body gamma radiation, beta burns and epilation from contamination of the skin, and slight internal absorption of radioactive material. Another 18 Rongelap people away on a nearby island (Ailingnae), where less fallout occurred, received only about half this exposure. Twenty-eight American servicemen on the island of Rongerik further away received about the same amount of radiation as did the 18 people on Ailingnae (about 70 r). Lastly, 157 Marshallese on Utirik, about 200 miles distant, received only about 14 r whole-body radiation. The fallout was not visible on this island and no skin effects were seen.

The exposed people were evacuated from these islands by plane and ship about two days after the accident and taken to Kwajalein Naval Base about 200 miles to the south, where they received extensive examinations for the following 3 months. In view of the generally negative findings on the American servicemen, they were returned to their duty stations. The Utirik people were repatriated to their home island, where the radioactivity was considered to be low enough for safe habitation. Because Rongelap Atoll was considered to be too highly contaminated, a temporary village was constructed for the Rongelap people on Majuro Atoll several hundred miles to the south, where they remained for the following 3½ years. In July 1957, after careful evaluation of remaining radiological hazards, Rongelap Island was found safe for habitation. A new village was constructed, and the Rongelap people were moved there by Navy ship. The present survey was therefore carried out at Rongelap Island.

SUMMARY OF PAST FINDINGS

Reports have been published on the findings of surveys made at the following times after exposure: initial examinations,[1] 6 months,[2] 1 year,[3] 2 years,[4] and 3 years.[5] The following is a brief summary of these findings.

During the first 24 to 48 hr after exposure, about ⅔ of the Rongelap people experienced anorexia and nausea. A few vomited and had diarrhea. Many also experienced itching and burning of the skin and a few complained of lachrymation and burning of the eyes. Following this, these people remained asymptomatic until about 2 weeks after the accident, when cutaneous lesions and loss of hair developed due largely to beta irradiation of the skin. It was apparent when the people were first examined, a few days after exposure, that the lymphocytes were considerably depressed and that significant doses of radiation had probably been received. In addition to the whole-body dose of radiation and the beta irradiation of the skin, radiochemical analyses of the urine showed that significant amounts of radioactive material had also been absorbed internally. The effects of the radiation can best be summarized under three headings according to the mode of exposure: penetrating irradiation, skin irradiation, and internal irradiation.

Penetrating Irradiation

The changes in the peripheral blood of the more heavily exposed Rongelap people who received 175 r will be reviewed below (see Figures 7, 9, 12 and Tables 3, 4, 5). The changes in the Ailingnae and Utirik groups were similar but less marked. Certain unexplained fluctuations have occured from year to year in the peripheral blood levels of the comparison populations as well as of the exposed groups. Depression of the peripheral blood elements as represented by mean population levels occurred as follows.

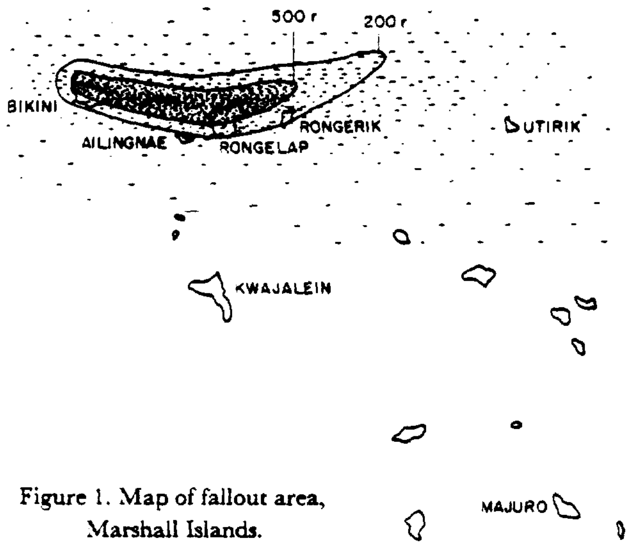

Figure 1. Map of fallout area, Marshall Islands.

Lymphocytes fell promptly and by the third day were about 55% of the control values in adults, and slightly lower in children. There was only slight recovery by six months. At 2 years, although further recovery was evident, the mean values of these cells were still found to be below the comparison population levels (75 to 80%). The 3-year examination showed that the lymphocytes were still somewhat below the level of the unexposed population.

Neutrophil levels fluctuated considerably during the first few weeks but fell gradually to a low of about 50% of control values by the 6th week after exposure. Slow recovery ensued, but at 6 months they were still slightly below the unexposed levels. However, by 1 year post-exposure they had returned to the level of the comparison population and have since remained so.

Platelets fell to about 30% of the unexposed values by the 4th week. By 6 months they had reached 70% of the controls; at 1 year the mean platelet count was still below that of the control population but higher than at the 6-month survey. Although further increases were apparent at the 2- and 3-year examinations, the levels were still below those of the comparison population.

Changes in hematocrit were not remarkable in any of the groups.

Clinical observations revealed no diseases processes or symptoms which could be attributed to radiation effects, aside from skin lesions, loss of hair, and early symptoms. The diseases encountered were no more severe or frequent in the irradiated than in the unirradiated population, even during the period of greatest depression of peripheral blood elements. Epidemics of chicken pox, measles, upper respiratory infections, and gastroenteritis have occurred, but apparently with no greater frequency or severity than in the unexposed populations. Two persons died in the exposed population. One was a 46-yr-old man with hypertensive heart disease which had been present at the time of exposure, who died two years after the accident. The second was a 78-yr-old man who died, three years after exposure, of coronary heart disease complicating diabetes. There was no apparent relationship between these deaths and radiation exposure, and mortality in the exposed group did not appear to have been greater than in the unexposed population.

It is difficult to evaluate the effects of exposure on fertility; however a number of apparently normal babies have been born, and there has been no discernible fall in the birth rate. Several miscarriages developed, but the incidence does not appear to be higher than in the unexposed populations. No opacities of the lens or other eye changes have been found that could be related to radiation. Studies on height and weight and bone age seemed to show a slight degree of retardation in growth and development in the exposed children. However, the small number of children involved, and a later finding that exact ages of some of the children were in doubt, permits no definite statements to be made.

Beta Irradiation of the Skin

No accurate estimate of the radiation dose to the skin could be made. Lesions of the skin and epilation appeared about 2 weeks after exposure, largely on parts of the body not covered by clothing. About 90% of the people had these burns and a smaller number developed spotty epilation. Most of the lesions were superficial; they exhibited pigmentation and dry, scaly desquamation and were associated with little pain. Rapid healing and repigmentation followed. Some lesions were deeper, showed wet desquamation, and were more painful; a few became secondarily infected and had to be treated with antibiotics. Repigmentation of the lesions gradually took place in most instances, and the skin appeared normal within a few weeks. However, in about 15% of the people, deeper lesions, particularly on the dorsum of the feet, continued to show lack of repigmentation with varying degrees of scarring and atrophy of the skin. At 3 years 14 cases continued to show some degree of residual skin change largely in the form of pigment aberrations with atrophy and scarring. Numerous histopathological studies have been made, and the changes found have been consistent with radiation damage. However, at no time have changes been observed either grossly or microscopically indicative of malignant or premalignant change.

The spotty epilation on the heads was short-lived, regrowth of hair occurring about 3 months after exposure and complete regrowth of normal hair by 6 months post-exposure. No further evidence of epilation has been seen.

An interesting observation was the appearance of a bluish-brown pigmentation of the semilunar areas of the fingernails and toenails in about 90% of the people beginning about 3 weeks after exposure. By 6 months, however, the pigmentation had largely grown out with the nail and had disappeared in most cases. The cause of this phenomenon has not been explained.

Internal Irradiation

Radiochemical analysis of numerous urine samples of the exposed population showed some degree of internal absorption of radioactive materials, probably brought about largely through eating and drinking contaminated food and water. Calculations of the body burdens of these materials, however, showed that the concentrations were too low to result in any serious effects, and the levels found at 2 and 3 years post-exposure were far below the accepted maximum permissible body level. The results of numerous radiochemical examinations of the urines over the past 4 years, and of gamma spectroscopy over the past 2 years, will be reviewed in greater detail below.

Present Survey

BACKGROUND MATERIAL

Organization

The medical team consisted of 8 physicians, 5 scientists, and 6 technicians from various laboratories in the United States. A Marshallese practitioner and 2 medical technicians from Majuro Atoll assisted the team, as did some of the Rongelap people (see Figure 2).

A group of six scientists from the University of Washington, headed by Dr. E.E. Held, accompanied the team to collect soil, marine, and plant

Figure 2. Medical team personnel.

Figure 3. LST Plumas County beached on Rongelap Island.

Figure 4. Personnel decontamination station aboard LST.

Figure 5. Steel room used for whole-body gamma spectroscopy.

Figure 6. Dispensary and examination buildings, Rongelap Island.

samples for radiochemical analysis. These studies are not yet complete and have not been included in this report.

The Navy kindly furnished a ship for the expedition, an LST, the USS Plumas County (Figure 3). The LST picked up medical equipment for the survey, including a 21-ton steel room for carrying out whole-body counts on the Rongelap people, about the middle of February at Hawaii and proceeded to Kwajalein. The medical team staged in Hawaii and flew via military air transportation to Kwajalein, boarded the LST, and proceeded to Rongelap Atoll. At Rongelap the LST was beached for easy accessibility to Rongelap village.

The 21-ton steel room, constructed at Brookhaven National Laboratory for use in whole-body gamma spectroscopy on the Marshallese in this and future surveys, measured 5 ft 8 in. by 5 ft 8 in. by 6 ft 6¼ in., with 4-in.-thick walls and ceiling and a 2-in.-thick floor. The room had been set up in the tank deck of the LST along with two 100-channel analyzers, a 5-in. crystal, and other accessory electronics equipment. A dressing room and shower facility had also been constructed on the tank deck for decontamination of personnel prior to whole-body counts. (See Figures 4 and 5.)

The histories were taken, and the physical and laboratory examinations were carried out at Rongelap village in the dispensary, school building, and council house (see Figure 6). The examinations lasted 3 weeks.

Difficulties Associated with the Examinations

Several difficulties associated with carrying out the examinations as well as interpreting the findings should be pointed out.

1) The language barrier made examinations difficult since very little English is spoken by the Marshallese. However, there were sufficient English-speaking Marshallese to assist the medical team in most instances in carrying out the examinations.

2) The lack of vital statistics or demographic data on the Marshallese imposed a serious difficulty in interpretation and evaluation of the medical data. Records of births, deaths, etc., have been made by the health aides or magistrates of the villages and supposedly forwarded to the district administrator; however, such records have been poorly kept or lost in most instances and thus vital statistics are practically nonexistent. Trust Territory officials are now attempting to assemble such data.

3) It is unfortunate that many of the Marshallese, particularly in the older age group, are uncertain of their exact ages, largely because few written records of birth are maintained.

Comparison Populations

During the first 2 years, two separate groups of Marshallese people were used for comparison, each of comparable size to the exposed Rongelap group and matched in age and sex. However, this population was found to be unstable, with a large attrition rate over the 2 years, which made it unsatisfactory. At the time of the 3-year survey, it was found that during the preceding 12 months the Rongelap population at Majuro Atoll had doubled because of the influx of relatives who had come back from other islands to live with them. These people had been away from Rongelap Atoll at the time of the accidental exposure. This group matched reasonably well for age and sex and was of comparable size; moreover, since these people were of the same stock genetically, they proved to be uniquely appropriate to serve as a comparison population. This group was therefore used at the 3-year examination as a control and again during the present survey.

PROCEDURES

History and Physical Examinations

Histories were taken by a Marshallese practitioner with particular emphasis on the interval history during the past year.

Complete physical examinations were carried out including examinations of the children for growth and development, anthropometric measurements, and x-ray examinations of the left wrist and hand for bone development studies; special examinations of the skin with color photography for selected lesions; ophthalmological studies including slit-lamp observations, visual acuity, and accommodation; and EGC and x-ray examinations as deemed necessary.

Laboratory Examinations

Hematological examinations included three complete blood analyses with WBC, differential, platelet counts (phase microscopy), and hematocrit (microhematocrit method) done at about weekly intervals.

The following examinations of the blood were made to determine genetically determined traits.

These studies were of interest in evaluating the homogeneity of the Rongelap people and learning something of their anthropological background.

Blood grouping studies. Studies of the blood groupings and gene distributions in the blood of 129 Marshallese were carried out by Dr. L.N. Sussman of the Beth Israel Hospital, New York City. The following systems were studied: ABO, MN, Rh-Hr, and Duffy, Kell, and Diego factors.

Haptoglobin studies. The method of Smithies was used, in which electrophoresis is carried out with a starch gel slab as supporting medium.[6] This analysis was made on 126 Marshallese blood samples by Dr. B.S. Blumberg of the National Institutes of Health, Bethesda, Maryland.

Hemoglobin types. The determination of hemoglobin types was made on 45 Marshallese blood samples by the method of Smithies[6] (starch gel zone electrophoresis). These studies were carried out by Dr. R.L. Engle, Jr. and Dr. G. Castillo of the Cornell University Medical Center, New York, N.Y.

Plasma proteins. Plasma protein determinations were carried out on all sera by the proteinometer technique.

Thyroid metabolism. In view of the exposure of the thyroid glands to radiation from the internally absorbed radionuclides, the metabolic state of the thyroid gland was of interest. These studies were made by Dr. J.E. Rall at the National Institutes of Health, Bethesda, Maryland. Protein-bound iodine determinations were carried out on 36 people in the exposed group and 24 in the comparison population. Butanol-extractable iodine content was measured in three people in each group, and thyroxine-binding proteins were determined in 12 persons in the comparison population.[7]

Serum vitamin B_{12} concentrations. In view of the general tendency to anemia in the population, serum vitamin B_{12} contents were measured to see whether they could be related to anemia. These determinations were carried out on the sera of 44 exposed Marshallese and 58 unexposed by Dr. D.W. Watkin of the National Cancer Institute, National Institutes of Health, Bethesda, Maryland. The method used was a modification of the USP XV *Lactobacillus leichmannii* method developed specifically for vitamin B_{12} assay in serum.[8]

Intestinal parasite survey. The generally high eosinophil counts and tendency to low hematocrits noted in both the exposed and unexposed Rongelap people led to an intestinal parasite survey to see whether parasitism might be responsible for these findings. Because of the generally accepted view that blood pictures of anemia and eosinophilia are more likely to be associated with helminthic rather than with protozoan infections of the intestinal tract, the methods used were directed primarily to detecting the former. The Beaver method of egg counting[9] and formalin-ether concentration[10] was used to obtain quantitative information on helminth infections. This is a simple, direct technique which is also useful in revealing protozoan infections, particularly when trophozoites are present. In addition, all stools were concentrated by the formalin-ether method to pick up infections too light to be detected by direct examination. One stool specimen per person was examined in each of 69 exposed persons and 112 unexposed. Specimens were brought to the laboratory shortly after being passed, and were generally examined within 1 hr. The methods used probably revealed ⅓ to ½ of the protozoan infections and perhaps 80% of the helminth infections likely to be found in these individuals had they been subjected to repeated examinations.

Serum and food sodium and potassium determinations. Because the Marshallese seem to have generally lower blood pressures and in view of the possibility that salt intake bears a causal relationship to essential hypertension in humans,[11,12] correlations between salt intake and incidence of hypertension were investigated by Dr. L.K. Dahl of Brookhaven National Laboratory. A morning sample (before breakfast) of urine was obtained on 13 exposed and 14 unexposed persons and analyzed for sodium and potassium level by flame spectrophotometry. A sample prepared meal was also obtained for similar analysis of the several items.

Determination of Body Burdens of Radionuclides

Radiochemical urine analyses. Urine samples, 24-hr as well as cumulative, were collected from 15 Rongelap people for radiochemical analyses carried out under the direction of Maj. K. Woodward and Col. J. Hartgering at the Walter Reed Army Institute of Research, Washington, D.C.

Whole-body gamma-ray spectroscopy. During this survey about 200 people were examined in the whole-body counter (21-ton steel room constructed at Brookhaven National Laboratory and carried out to the Islands) for body levels of gamma emitting nuclides. Unfortunately, the data on these counts as well as considerable medical equipment were lost in the Pacific Ocean when the cargo had to be jettisoned from a plane which developed engine trouble. A return trip to Rongelap Island was made two months later (May 1958), and about 100 Rongelap people were again counted in the steel room. Details of the procedures used and the results will be described below.

FINDINGS

Living Conditions

During the past year the Rongelap inhabitants have become well adjusted to life in their new village, which was completely rebuilt, with well constructed houses far superior to the old ones. An interesting sidelight is that some of the people, particularly the older ones, prefer to live beneath their houses, probably because it is cooler and they prefer not to climb the steps.

During the 8 months since the people returned, copra production was being satisfactorily re-established, but it had not reached full capacity. The establishment of an agricultural program was proceeding disappointingly slowly. At this writing it is understood that the Trust Territory is sending a full-time agriculturist to implement this program.

Adequate water is available on Rongelap from the concrete water catchment cisterns from the roofs of nearly all the houses. Flies are quite prevalent. Most of the people still cook outdoors rather than in the screened cook-houses built for them. Scraps of food around the cooking area probably predispose toward flies. The screened-in latrines are a big improvement, and it is hoped that the children will make greater use of them. This point has been emphasized to the people in order that intestinal parasites may be better controlled. The island is heavily infested with rats and some sort of extermination program is indicated.

The diet is extremely limited in variety, although caloric intake appears to be adequate. The chief source of carbohydrate is rice and a small amount of flour. Protein is derived largely from fish with an occasional supplement of canned meat. The fat intake is mostly from coconut meat. Vitamins are obtained mainly from coconuts, pandanus (when available), and fish. In view of the importance of diet in relation to certain puzzling clinical laboratory findings, the following more detailed information is presented.

Fish is the main source of protein. It is eaten fresh, dried, or salted, several times weekly and frequently daily. A great deal more is eaten fresh than otherwise. The liver is included. Among ***canned meats***, corned beef is well liked as well as salmon and sardines. About one can (perhaps two) is eaten weekly per person. ***Other meats*** include pigs and chickens which run loose on the island and are eaten on rare occasions. Clams (particularly the giant clams) are eaten when they can be found; however, they are not plentiful now. Land crabs are considered a delicacy, but eating them is forbidden at this time because of their high Sr^{90} level. (This is the only forbidden dietary item.)

Local plant products. Coconuts are an important item of the diet, eaten green or ripe. About three green coconuts per day are consumed per person, both milk and meat. Ripe coconut is eaten with meals either as such or grated onto rice and fish. ***Pandanus*** is available during the summer and fall. The fruit is eaten raw by sucking the sweet juice from the fibrous segments. The juice is also squeezed out and used to flavor arrow root flour and to make a candy known as "jenkum." This fruit is probably a major source of vitamin A and possibly C. ***Arrowroot*** is grated to form a starchy flour, which is cooked into a mushy, tapioca-like material. It is available principally in the winter months. ***Breadfruit***, a starchy fruit, is not abundant on Rongelap but is eaten when available. ***Rice, salt, sugar, flour, tea,*** and ***canned meats*** are imported. Rice is a mainstay eaten three times a day. Sugar is used to sweeten tea. A little salt is used in cooking rice and bread, but is usually in short supply and is rarely used on prepared food. Bread and pancakes are frequently eaten.

Interval Medical History

The general health of the Rongelapese has been good during this past year. Six children (4 exposed and 2 unexposed) presumably had infectious hepatitis during November and December 1957. No other major epidemics or diseases were reported. Abdominal pain and diarrhea were among the commonest complaints, and were probably associated with the eating of food kept several days without refrigeration. The large number of flies may also play a part in the prevalence of this condition. A complaint of night blindness of several months duration among 10 children and 1 adult was investigated and is reported below. Common colds, fungus infections of the skin, and impetigo were also common complaints for which the health aide was consulted.

During the past year healthy babies were born to 4 irradiated women and 6 unexposed women. The exposed and unexposed groups each contain 19 women of child-bearing age (15 to 44 years). Three miscarriages occurred in the exposed women, two at 3 months and one at about 6 months. In all three cases this was the second miscarriage since exposure. However, two of the women have had one normal pregnancy since the accident. One of the unexposed women had a miscarriage, and another had a full-term baby that died within a month, apparently of diarrhea of infancy. (Between the March survey and the return survey in May 1958, one exposed woman had a full-term baby that died shortly after birth of unknown cause.)

One death, presumably due to coronary thrombosis, occurred in July 1957, that of a 78-yr-old diabetic male. No autopsy was obtained. One unexposed 65-yr-old male died in January 1958, presumably of arteriosclerosis and senility. No autopsy was obtained.

Physical Examinations

Examinations showed the general physical condition of the people to be satisfactory. Grossly, nutritional status was also satisfactory, in spite of the dietary restrictions referred to above. However, 6 children (all in the unexposed group) showed mild to moderate degrees of hemeralopia when put through an obstacle course test at night. All were treated with vitamin A and recovered rapidly. This evidence of mild vitamin A deficiency is understandable after study of their diet. At that time of the year pandanus was not ripe and other sources of vitamin A were scarce.

Table 1 lists the major diseases noted in the exposed and unexposed people. The diseases found were present with about the same frequency in the unexposed and exposed groups. No malignant conditions were noted.

Table 1

Incidence of Various Disease States Among the Marshallese (52 exposed adults and 55 unexposed adults examined)

	Exposed	Unexposed
Congenital Anomalies		
Short 5th finger	1	2
Prominent ulnar styloid process	3	2
Congenital dislocated hip	0	1
Heberden's nodes	1	1
Adrenogenital syndrome	0	1
Pilonidal sinus	2	0
Hernia, umbilical	0	0
Congenital nystagmus	0	1
Congenital facial asymmetry	0	1
Other Abnormalities Found		
Cheilosis	1	0
Tinea versicolor	4	7
Kyphoscoliosis	7	3
Impetigo and ecthyma	1	0
Healed yaws	1	1
Bronchitis	9	5
Hypertension	5	6
Arteriosclerosis, peripheral	2	1
Osteoarthritis	2	4
Obesity	2	2
Chronic cervicitis	0	2
Cystocele and rectocele	2	2
Emphysema	4	0
Uterine fibroids	0	2
Goiter	0	2
Hemorrhoids	0	1
Hepatosplenomegaly	1	0
Abnormal knee-jerks	0	1
Keloid	1	1
Leprosy	1	0
Functional heart disease	1	0
Rheumatoid arthritis	0	1
Ovarian cyst	0	1
Anal fistula	0	1
Dupuytren's contracture	0	1
Senile vaginitis	0	2
Hallux valgus	0	1
Leontiasis osseum	0	1
Urethral caruncle	1	0

Physical examination of the children revealed few major medical disorders in either the exposed or unexposed groups. One exposed child had inactive rheumatic heart disease with evidence of polyvalvular involvement (reported previously). He showed no further evidence of decompensation such as had occurred 3 years previously and was able to keep up with other children in their play. Extensive molluscum contagiosum and superficial pustules on the legs were common. An occasional child had palpable cervical nodes, but tonsilar hypertrophy was uncommon. Xeroderma, cheilosis, and glossitis were not seen.

In the exposed adults, one case of auricular fibrillation of several years standing in a 30-yr-old male continued asymptomatic. The case of leprosy showed no progression of the lesions of the hands and feet. Marked improvement was noted in the case of an 80-yr-old man who had suffered a cerebral accident 2 years previously; much of the unilateral paralysis had disappeared. Three other aged exposed people, two females, one supposedly 101 years of age and one 75, and one male 79, were obviously becoming more infirm. They rarely left the seclusion of the mats beneath their houses. Only one unexposed person was in this same age range, a male aged 84 who was still able to move about fairly well.

In April 1958, after the March survey, a death occurred in a 36-yr-old male from the Ailingnae group, which had received about 69 r of gamma irradiation from the fallout in 1954. He had complained in March of epigastric pain, anorexia, and loss of vigor. Physical examination at that time was essentially negative except for epigastric tenderness. A tentative diagnosis of peptic ulcer was made, although it could not be substantiated since x-rays were not available. He improved on an ulcer diet including canned milk. About 3 weeks later, after the survey team had left, he became acutely ill and was transferred to the Naval Hospital at Kwajalein, where he died the following day. The entire skin and mucous membranes of the mouth were covered with uniocular vesicles and bullae. Autopsy revealed acute bilateral pneumonia of unknown origin and passive congestion of the liver. A diagnosis of varicella was made. Microscopic examination of the skin lesions showed inclusion bodies typical of varicella.*

The striking thing about the physical examinations in both the exposed and unexposed people was the relative paucity of findings associated with degenerative diseases. While the group under observation is too small to permit any valid statistical analysis, the clinical impression was that diseases such as atherosclerosis and hyptertension were considerably less common and of lesser severity than in a comparable group of our population. Among the 114 people 50 years old or less, none had a blood pressure greater than 140/90. Among the 23 persons older than 50 years, 6 had pressures ranging from 160 to 220 systolic and 90 to 110 diastolic, and 2 had systolic elevations of 160 to 170 but diastolic pressures of 75 to 80. The groups were too small for these findings to be evaluated relative to American statistics, but it can be said that theblood pressures do not exceed those commonly found and probably are lower.

There was a general feeling that conditions like hernia, varicose veins, hemorrhoids, and vaginal prolapse were much less common than one might anticipate in examining a random group of people of similar age in our society. One interesting finding was a relatively high incidence of kyphosis. While this is common in older people in our own population, it was particularly striking in the Marshallese, because it appeared to be localized to the lower thoracic and lumbar region. Fungus infections of the skin, particularly Tenia versicolor, were widespread.

Growth and Development Studies

Cross sectional data on height and weight and bone age determinations for the 2- and 3-year surveys gave an impression of lag in growth and development in the exposed children compared with unexposed children of the same age. However, in an attempt to obtain more accurate birth dates of the children for the 4-year survey, the ages of some of the children, previously thought to be well established, were found to be questionable. The absence of recorded birth information seriously complicates the determination of the accuracy of given chronological ages and dates of birth. More definitive evaluation of data will be possible when verification of birth dates is completed. Detailed geneological and biological histories are being compiled to establish the most probable birth date of each child. (Unfortunately, the 1958 roentgenograms of the wrist and knee, intended for assessment of osseous maturation, were lost at sea.)

In addition to cross sectional studies, longitudinal studies of incremental growth data and bone maturation studies over the period since exposure will be undertaken when the ages of the children are better established.

Ophthalmological Examinations

Table 2 shows the major ophthalmological findings. Generally the Rongelap people, exposed and unexposed, showed superior vision and accommodation. The majority of disorders were found in the conjunctiva, cornea, and lens. Irritation of the eyes from bright tropical sunlight and exposure to coral dust probably play a part in the high incidence of conjunctival and corneal defects.

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*We are grateful to Capt. B.E. Bassham, (MC) USN, for doing the autopsy, and to Dr. S.W. Lippincott and Dr. H.A. Johnson of Brookhaven National Laboratory for the histological examination.

Table 2

Ophthalmological Findings (% incidence)

	Exposed	Unexposed
Pterygium	30.5	16.3
Pinguecula	24.4	15.3
Corneal pigment	6.1	4.8
Corneal scars	9.8	8.6
Arcus senilis	29.2	12.5
Dacryocystitis	1.2	0.0
Phthisis bulbi	3.6	1.0
Nystagmus	0.0	1.0
Pannus	1.2	0.0
Strabismus	7.3	1.0
Molluscum contageosum	3.6	3.8
Argyll-Robertson pupil	1.2	0.0
Keratitic precipitates	1.2	0.0
Cataracts	12.1	0.0
Aphakia	6.1	2.9
Vitreous opacities	8.5	0.0
Retinal arteriosclerosis	10.7	9.6
Choroidal scars	4.8	1.9
Macular degeneration	2.4	0.0
Drüsen	1.2	2.4
Congenital anomalies	3.6	1.0
Macrocornea	15.9	14.4

Slit-lamp observations revealed no opacities of the lens in the exposed people like those seen in the irradiated Japanese.[13,14] Also, no differences between the exposed and the unexposed groups were noted in visual acuity or accommodation.[15] A high incidence of such conditions as pinguecula and pterygium has been noted in the exposed group. This finding may have no significance, but it is not known whether the exposure of the eyes to beta irradiation in 1954 from fallout could have played an etiological role.

It is of interest that no cases of glaucoma were noted. The incidence of myopia was very low, as was the incidence of retinal arteriosclerosis, squint, and deficiency in color vision. Of interest was the finding of a large number of adults and children with large corneas, and anomalies of the retinal vascular patterns.

Examination of the Skin

Twelve cases continued to show residual evidence of beta lesions of the skin. These were for the most part mild and consisted of slight atrophy and pigment aberration. A few lesions showed scarring and atrophy with slight adhesion of the skin to subcutaneous tissues, and lack of pigment formation. However, improvement was noted in most lesions and in no case was there any aggravation of the lesion or tendency to develop chronic radiation dermatitis, or any change that appeared to be malignant or premalignant. In view of the generally favorable progress of the lesions, no biopsies for microscopic study were taken on this survey.

Laboratory Examinations

Hematological – Routine. The basic hematological data are presented in Tables 3 to 6. The mean blood counts of the exposed people and of the various comparison populations are shown for the 4-year period since March 1954. In Figure 7 are plotted the mean of two separate absolute blood counts on the exposed groups carried out during the 4-year survey, along with mean levels for other post-irradiation intervals; the open circles represent the mean values for the comparison population. The blood data have been classified as in the past according to age and sex.* The following represent the findings on the more heavily exposed Rongelap group compared to those on the unexposed Rongelap people.

WBC. The mean WBC was slightly higher in both exposed and unexposed groups in both the <5 and >5 year age groups compared with the levels a year ago (see Table 3 and Figure 7). The exposed level is about the same as the control level.

The ***neutrophils*** showed a further slight decrease in the exposed group since a year ago (Table 3, Figure 7). These counts in most cases reached a peak at 1 to 2 years post-exposure and declined during the following 2 years. In fact the counts this year are the lowest since the maximum depression occurred at 6 weeks post-exposure. In spite of this observation, the counts show little difference (5% less) from those in the unexposed group. A scattergram (Figure 8) age distribution

	Sex	Age, yr	Rongelap	Ailingnae	Unexposed Rongelap
*Leukocytes:	both	<5	8	2	5
	both	>5	56	16	80
Platelets:	M	<10	9	2	10
	M	>10	22	5	40
	F	all ages	33	11	34
Hematocrits:	M	<15	12	2	17
	M	>15	19	5	34
	F	all ages	33	11	34

of the counts compared with the mean curve of the unexposed neutrophil counts shows that children about 12 years of age and below have more counts below than above the mean curve of the unexposed children of the same age range. However, above this age the distribution of counts is about the same.

The mean of the ***lymphocyte counts*** shows an increase since last year's counts of 33% in the exposed groups (Figure 9). It is this increase in lymphocytes that accounts for the rise in the total white count noted above. The lymphocytes in the exposed group are at the highest point since exposure. However, a scattergram (Figure 10) shows that more of the counts in the exposed group are below than above the mean unexposed curve. An accumulative percentage distribution of the counts (Figure 11) shows the exposed curve still to be slightly displaced to the left.

Eosinophil and ***monocyte*** and ***basophil*** counts are about the same in the exposed as in the unexposed groups. The eosinophil counts were quite high in both exposed and comparison populations, but were about the same in the two groups. In their differential counts, 45% of the exposed and 55% of the unexposed had eosinophils of 5% or greater.

Mean ***platelet counts*** have shown further recovery this year in both sexes of the exposed group compared with last year's results (Figure 12). As

Table 3

Rongelap Group and Control Mean Blood Counts by Day and by Age

	WBC ($\times 10^{-3}$)		Neutrophils ($\times 10^{-3}$)		Lymphocytes ($\times 10^{-3}$)		Platelets ($\times 10^{-4}$)				Monocytes ($\times 10^{-2}$)		Eosinophils ($\times 10^{-2}$)	
Postexposure day	<5	>5	<5	>5	<5	>5	Male <10	Male >10	Female all ages	Total group	<5	>5	<5	>5
3	9.0	8.2	6.4	4.7	1.8	2.2	—	—	—	—	0.8	0.3	0.1	0.7
7	4.9	6.2	—	—	—	—	—	—	—	—	—	—	—	—
10	6.6	7.1	3.5	4.5	2.6	2.1	28.2	22.7	24.9	24.8	2.9	1.7	1.6	1.6
12	5.9	6.3	3.5	3.9	2.1	1.7	—	—	—	—	4.2	5.4	1.9	1.9
15	5.9	6.5	3.2	4.1	2.4	1.9	27.1	21.3	21.7	22.5	3.0	2.3	1.1	1.3
18	6.7	7.2	3.4	4.7	2.4	2.1	21.8	19.1	21.8	21.0	2.7	1.7	3.5	1.6
22	7.0	7.4	4.3	5.0	2.6	2.1	16.8	14.6	15.2	15.3	1.9	2.0	2.3	1.8
26	5.7	6.1	3.0	3.9	2.3	1.8	13.2	12.9	10.9	11.9	1.9	1.6	1.8	1.3
30	7.6	7.8	4.0	5.3	3.2	2.1	14.1	12.3	11.8	12.3	1.5	0.9	3.4	2.2
33	6.5	6.2	3.1	3.8	3.2	2.0	17.9	16.6	15.1	16.0	1.7	1.6	2.6	2.2
39	5.7	5.5	3.0	3.3	2.6	2.0	25.5	22.0	22.4	22.8	0.9	0.9	0.5	1.0
43	5.2	5.2	2.0	2.6	2.9	2.3	26.8	20.9	23.2	23.2	1.1	1.1	1.4	0.8
47	5.9	5.8	2.6	3.3	3.1	2.4	24.6	20.6	23.9	23.1	1.0	1.0	1.1	0.5
51	6.7	5.6	2.6	3.5	3.4	2.1	22.1	17.5	21.2	20.3	2.5	1.6	0.8	0.7
56	7.0	6.0	3.5	3.5	3.7	2.4	—	—	—	—	1.7	1.2	—	—
63	7.7	6.0	3.9	3.6	3.7	2.3	23.1	18.2	20.2	20.1	0.5	0.9	0.3	0.6
70	7.6	6.5	3.8	4.0	3.3	2.2	—	—	—	—	—	—	3.4	1.9
74	—	—	—	—	—	—	26.2	21.7	24.7	24.1	—	—	—	—
6-mo survey	8.5	6.6	4.6	4.2	3.6	2.2	24.4	20.3	23.2	22.6	1.4	1.1	2.5	1.6
1-yr survey	10.1	8.1	4.7	4.8	4.6	2.8	26.6	19.5	27.6	24.9	0.7	1.3	6.7	2.8
2-yr survey	11.8	8.6	5.9	4.8	4.7	3.1	30.0	21.4	25.5	24.7	2.7	1.5	9.6	5.3
3-yr survey	8.6	6.9	4.1	3.7	3.7	2.7	32.0	22.1	28.1	—	1.2	0.7	6.4	4.5
4-yr survey	8.9	7.5	3.3	3.4	4.6	3.6	32.5	27.1	30.8	—	1.5	1.1	7.9	4.0
Majuro controls	13.2	9.7	4.8	4.8	7.4	4.1	41.2	25.8	36.5	33.4	2.0	2.0	9.5	4.7
Rita controls, 6 mo	10.7	7.6	5.4	5.2	4.7	3.7	35.0	27.3	30.9	30.4	1.9	1.7	4.2	4.8
Rita controls, 1 yr	—	—	—	—	—	—	37.5	24.5	29.4*	27.6	—	—	—	—
Rita controls, 2 yr	14.0	8.9	7.0	4.4	5.6	3.6	35.5	24.2	31.2	29.5	1.4	1.5	12.8	6.6
Rongelap controls, 3 yr	9.8	6.9	4.0	3.4	4.7	2.9	32.6	26.9	30.0	—	1.4	0.7	6.2	4.0
Rongelap controls, 4 yr	11.2	8.0	4.0	3.6	6.2	3.7	38.8	30.7	34.0	—	2.3	1.1	7.0	4.5

*Excluding pregnancy.

with the lymphocytes, the platelet counts are the highest yet attained since exposure. However, the unexposed group also showed an increase in mean platelet count compared with last year; but the exposed group levels are still significantly below the unexposed (males, <10, −16%; >10, −11%; and females, all ages, −9%). This is also borne out by the following findings: (1) 22% of the exposed group have levels below 250,000 compared with only 7% in the unexposed people; (2) the scattergrams (Figures 13 and 14) show more counts below than above the unexposed mean curve in both sexes; and (3) the accumulative percentage distribution curve (Figure 15) is displaced to the left of the unexposed curve.

Erythropoietic function as evidenced by hematocrit levels shows little difference between the exposed and the unexposed groups, and neither group shows significant change since last year. The exposed males >15 years of age continue to show slightly lower hematocrit values than do unexposed males of the same age (see Table 6). However, the other blood elements in this group of males do not appear lower than in the unexposed group. A general anemic tendency in the Marshallese (combined exposed and unexposed groups) is borne out by the finding that 78% of the females have hematocrits of 36% or less and 54% of the males have hematocrits of 38% or lower.

Counts in the Ailingnae group. From Table 4 it can be seen that the counts in the 18 people of this group averaged nearly the same for the various blood elements as did the counts in the more heavily exposed group. Lymphocyte levels and platelet levels in the males were slightly lower, however. These same differences were noted at the time of the 3-year survey.

Individual counts. In reviewing the individual peripheral blood counts, lower levels were found in more exposed individuals than in the unexposed group. Those showing generally lower counts in the two groups are listed in Table 7.

Table 4

Ailingnae Group and Control Mean Blood Counts by Day and by Age

	WBC ($\times 10^{-3}$)		Neutrophils ($\times 10^{-3}$)		Lymphocytes ($\times 10^{-3}$)		Platelets ($\times 10^{-4}$)				Monocytes ($\times 10^{-2}$)		Eosinophils ($\times 10^{-2}$)	
Postexposure day	<5	>5	<5	>5	<5	>5	Male <10	Male >10	Female all ages	Total group	<5	>5	<5	>5
3	6.0	7.0	3.0	5.0	2.8	2.2	—	—	—	—	0.8	1.6	0.5	0.4
7	5.5	6.8	—	—	—	—	—	—	—	—	—	—	—	—
10	6.3	7.3	4.2	4.2	1.9	2.2	22.5	22.6	20.9	21.5	3.8	2.1	2.6	1.6
12	6.3	7.6	1.8	4.7	3.1	2.2	—	—	—	—	3.4	5.8	4.4	2.6
15	7.1	7.0	2.3	4.5	4.2	2.2	29.0	20.2	24.6	23.9	3.7	2.6	2.3	1.4
18	6.8	7.8	2.9	5.0	3.5	2.4	27.5	21.7	24.9	24.3	2.3	1.5	3.2	2.3
22	8.9	8.7	5.3	5.4	2.7	2.9	23.5	17.0	22.9	21.3	1.5	2.4	5.8	2.4
26	8.4	7.0	4.8	4.4	3.2	2.2	20.0	13.8	17.4	16.7	2.3	2.4	0.6	1.6
30	9.6	8.6	5.3	6.2	3.7	2.0	19.5	12.8	18.2	16.8	1.9	1.9	4.1	2.0
33	7.7	7.8	3.3	5.2	3.5	2.2	24.0	15.8	22.7	17.6	2.8	2.2	6.0	1.9
39	7.5	6.2	2.9	4.2	4.7	1.9	26.5	20.8	27.0	25.2	1.1	1.7	2.7	1.6
43	6.9	6.5	2.7	3.6	3.9	2.7	28.0	19.6	25.3	24.0	0.6	1.4	2.8	0.6
47	7.3	6.7	3.5	3.8	3.4	2.7	27.0	20.0	26.1	24.5	2.2	1.9	1.5	0.7
51	8.4	6.3	3.8	3.6	4.0	2.2	32.0	18.2	25.0	23.9	2.7	2.8	2.2	1.0
54	4.6	6.3	2.8	3.5	3.2	2.5	37.0	19.8	23.8	24.2	1.5	1.9	1.8	0.8
6-mo survey	7.7	6.5	4.8	3.9	2.7	2.2	25.2	19.2	23.9	22.7	1.1	1.4	1.5	2.2
1-yr survey	11.1	7.8	4.2	4.7	6.5	5.6	38.7	21.4	28.3	27.5	1.0	1.1	1.7	2.2
2-yr survey	11.0	9.1	4.9	5.1	4.8	3.2	51.2	17.4	26.4	26.7	3.6	1.4	9.6	6.4
3-yr survey	12.1	7.0	5.5	3.9	5.6	2.6	40.8	22.4	31.2	—	3.0	0.7	5.3	3.7
4-yr survey	11.5	7.5	2.8	3.7	7.0	3.3	33.2	24.7	33.6	—	2.2	1.1	12.6	4.2
Majuro controls	13.2	9.7	4.8	4.8	7.4	4.1	41.2	25.8	36.5	33.4	2.0	2.0	9.5	4.7
Rita controls, 2 yr	14.1	8.9	7.0	4.4	5.6	3.6	35.5	24.2	31.2	29.5	1.4	1.5	12.8	6.6
Rongelap controls, 3 yr	9.8	6.9	4.0	3.4	4.7	2.9	32.6	26.9	30.0	—	1.4	0.7	6.2	4.0
Rongelap controls, 4 yr	11.2	8.0	4.0	3.6	6.2	3.7	38.8	30.7	34.0	—	2.3	1.1	7.0	4.5

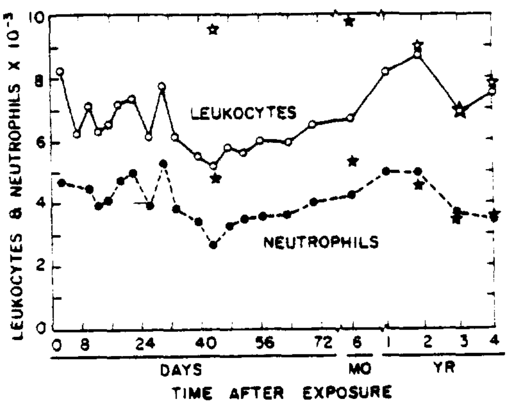

Figure 7. Mean neutrophil and white blood cell count of exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean value of control population.

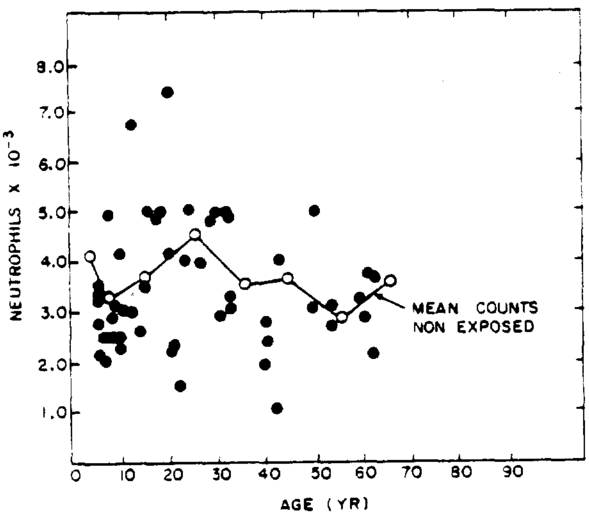

Figure 8. Neutrophil scattergram of individual counts plotted against age; Rongelap, age >5, 4 years post-exposure. Open circles represent mean counts of comparison population.

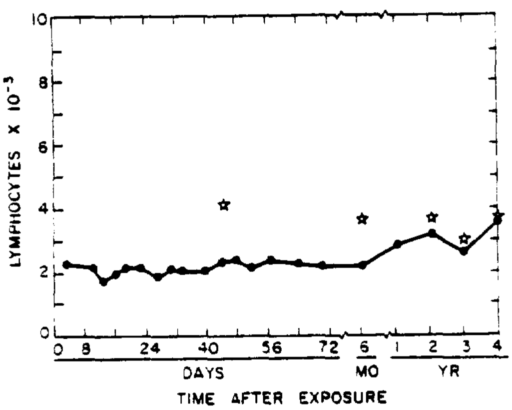

Figure 9. Mean lymphocyte values for exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean values of control population.

Table 5

Hematocrits

Postexposure day	Rongelap Male <15	Rongelap Male >15	Rongelap Female all ages	Ailin[...] Male <15	Ailin[...] Mal >1[...]
22	37.5	43.9	39.0	37.5	43.[...]
26	36.3	41.6	37.5	36.5	43.[...]
30	37.9	42.2	37.1	36.0	44.[...]
33	37.4	42.2	36.8	35.5	43.[...]
39	37.8	42.4	37.4	35.0	45.[...]
43	37.3	41.8	37.6	36.0	45.[...]
47	39.0	43.4	38.3	—	46.[...]
6-mo survey	38.0	41.7	38.2	37.5	40.[...]
1-yr survey	37.5	41.1	36.9	33.0	44.[...]
2-yr survey	38.7	41.2	38.1	35.7	44.[...]
3-yr survey	35.6	38.7	35.4	37.5	40.[...]
4-yr survey	35.6	41.0	35.8	36.1	43.[...]
Majuro controls	39.6	46.0	39.9	39.6	46.[...]
2-yr controls	38.9	42.1	39.8	38.9	42.[...]
3-yr controls	35.6	41.0	35.9	35.6	41.[...]
4-yr controls	35.5	42.8	35.1	35.5	42.[...]

Table 6

Mean Blood Count by Age and Sex
for the Exposed and Control Groups, 1958

	Rongelap		Ailingnae		U[...]
WBC ($\times 10^{-3}$)					
4 - 5	8.9 (7)*±1.4**		11.5 (1)		11.[...]
>5	7.5 (48)±1.6		7.5 (15)±1.8		8.[...]
Neutro ($\times 10^{-3}$)					
4 - 5	3.3	±0.9	2.8		4.[...]
>5	3.4	±1.2	3.7	±1.0	3.[...]
Lymph ($\times 10^{-3}$)					
4 - 5	4.6	±1.2	7.0		6.[...]
>5	3.6	±1.1	3.3	±1.2	3.[...]
Mono ($\times 10^{-2}$)					
4 - 5	1.5	±1.0	2.2		2.[...]
>5	1.1	±0.6	1.1	±0.9	1.[...]
Eosin ($\times 10^{-2}$)					
4 - 5	7.9	±5.2	12.6		7[...]
>5	4.0	±2.1	4.2	±4.7	4.[...]
Platelets ($\times 10^{-4}$)					
Males 4 - 10	32.5 (8) ±8.6		33.2 (2)		38[...]
Males >10	27.1 (18)±5.8		24.7 (4) ±2.3		30[...]
Females > 3	30.8 (29)±7.0		33.6 (10)±7.4		34[...]
Hematocrit					
Males 3 - 15	35.6 (11)±1.5		36.1 (2)		35[...]
Males >15	41.0 (15)±2.4		43.1 (4) ±2.8		42[...]
Females > 4	35.8 (29)±1.5		35.7 (10)±3.8		35[...]

*Number of individuals.
**Standard deviation.

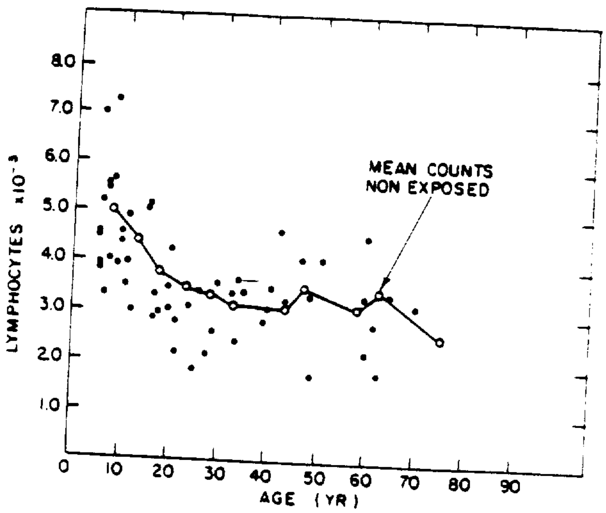

Figure 10. Lymphocyte scattergram of individual counts plotted against age; Rongelap, age >5, 4 years post-exposure. Open circles represent mean counts of comparison population.

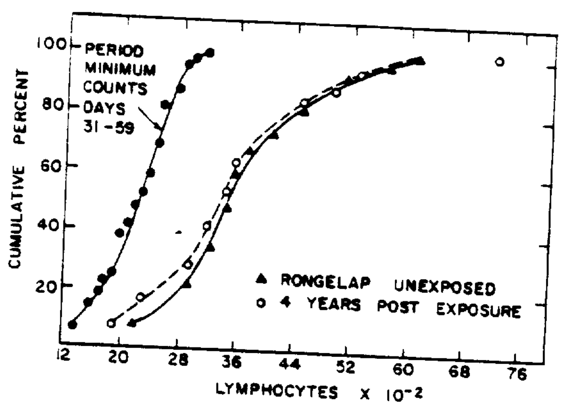

Figure 11. Cumulative distribution curve, Rongelap lymphocytes, age >5.

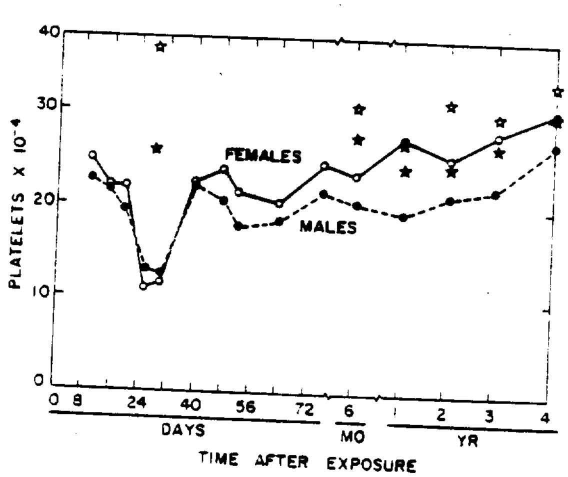

Figure 12. Mean platelet values for exposed Rongelap people from exposure through 4 years post-exposure. Stars represent mean values for control populations.

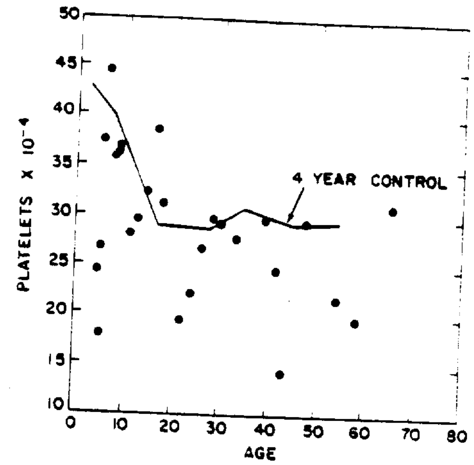

Figure 13. Platelet scattergram, males, of individual counts plotted against age. Solid line represents values for control population.

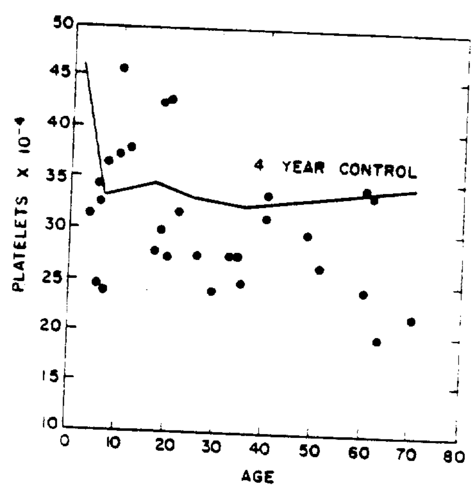

Figure 14. Platelet scattergram, females, of individual counts plotted against age. Solid line represents values for control population.

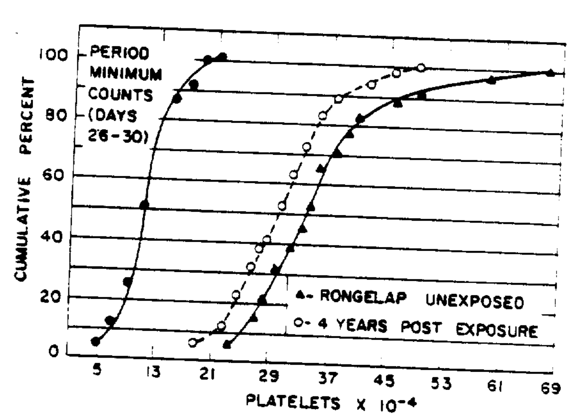

Figure 15. Cumulative distribution curve, Rongelap platelets, all ages.

Hemopoietic reserve. It was of interest to determine whether the hemopoietic reserve of the exposed Marshallese was equal to that of the unexposed group. Means were sought to stimulate or challenge the marrow in regard to white cellular elements, erythroid cells, or platelets, but no feasible methods have been found. However, advantage was taken of a possibility that effects of the natural stress of menstruation and childbearing in the women 15 to 45 years of age might be reflected in differences in levels of their peripheral blood elements. The blood levels in this group of females were compared with those in the same age group of unexposed females, and the differences were then compared with the differences between exposed and unexposed men in the same age groups. Irradiated women and men, 15 to 45 years of age, were found to show the following percentage differences from the unexposed women and men of the same age group: neutrophils, females −5%, males +3%; lymphocytes, females −6%, males −15%; platelets, females −6%, males −7%; hematocrit, females +2%, males −6%. From these data, it did not appear that exposed women showed any lower levels of peripheral blood elements than did the exposed men compared with the unexposed groups, and the stress of these female functions did not appear to cause any noticeable effect.

Hematological Studies of Genetically Determined Traits. Blood grouping studies. The following is taken from a report by Sussman et al.[16] on blood groupings in the Rongelapese.

1) ABO System:

The groupings in this system were as follows.

Group	No.	%	Gene Frequency	
O	75	58.1	0.762	$p_c = 0.789$
A_1	24	18.6	0.114	$q_c = 0.116$
A_2	0	0		
B	19	15.0	0.093	$r_c = 0.095$
A_1B	10	7.4		
A_2B	1	0.8		

The unusual finding of a single A_2B was verified by testing with several absorbed B antisera, as well as with the lectin of *Dolichos biflorans*.[17] The total absence of A_2 genes in Eastern Asia, Australia, and Indonesia has been repeatedly noted.[18,19] Inquiry into the family background of the single A_2B native failed to reveal any significant information leading one to suspect admixture.

2) MN System:

This blood group system was distributed as follows.

	No.	%	Gene Frequency
M	8	6.2	0.14
MN	20	15.5	
N	101	78.3	0.86

The low frequency of the M gene has been noted in the Marshall Islanders by many investigators.[20] The frequencies obtained in this study are among the lowest encountered.

3) Rh-Hr System:

A most unusual distribution was noted in this system. Tests were performed with anti Rh_o (D), rh′ (C), rh″ (E), hr′ (c) and hr″ (e) sera. The results are as follows.

Phenotype	No.	%	Chromosome Frequency
Rh_1Rh_1	126	97.7	$R^1 = 98.5$
Rh_1rh	3	2.3	

The chromosome frequency of 98.5% for R^1 is the highest reported for any ethnic group. The complete absence of any rh negative persons in these and related series leads one to suspect that the true genotype of the bloods giving a positive reaction with anti hr′ (c) serum is most probably R^1R^o. The occasional finding of an Rh_o person by Simmons[20] supports this interpretation. In the present series of 125 there were no bloods that reacted with rh″ (E) antiserum.

Table 7

Case No.	Age	Sex	WBC ($\times 10^{-3}$)	Neut. ($\times 10^{-3}$)	Lymph. ($\times 10^{-3}$)	Plate. ($\times 10^{-3}$)
			Exposed			
68	53	M	4.6	2.2	1.7	199
73	22	M	4.7	2.3	2.1	198
12	23	F	4.5	1.6	2.8	316
16*	42	M	4.5	2.2	1.8	247
58	63	F	5.6	2.2	3.2	219
30	63	F	5.5	3.7	1.7	197
11	54	M	5.6	3.2	2.2	218
			Unexposed			
878	39	M	5.0	2.2	2.2	229
854	58	F	5.1	2.2	2.7	383

*Ailingnae.

Table 8

ABO, MN, Rh-Hr, and Duffy-Kell-Diego Frequency Among Marshallese and Polynesians

		ABO system							MN system				
		Group				Gene frequency			Type			Gene frequency	
	No.	O	A	B	AB	p_c	q_c	r_c	M	MN	N	m	n
Marshallese (present study)	129	58.1	18.6	15	8.2	0.789	0.116	0.095	6.2	15.5	78.3	0.14	0.86
Marshallese (Simmons[20])	678	52.2	21.4	121.1	5.3	0.723	0.135	0.134	(10)	(19)	(71)	0.22	0.78
Polynesians (Simmons and Graydon[21])	138	39.1	60.9	0	0	0.626	0.374	0.10	19.6	47.8	32.6	0.435	0.565

	Phenotype Rh-Hr				Gene frequency			Duffy, Kell, Diego		
	Rh_1Rh_1	Rh_1rh	Rh_2	Rh_1Rh_2	R^1	R^2	R^0	Fy^a+	K+	Di^a+
Marshallese (present study)	97.7	2.3	0	0	0.985	0	0.15	89.2	0	0
Marshallese (Simmons[20])	90.6	0.7	0.3	8.0	0.951	0.04	0.006	100	-	-
Polynesians (Simmons and Graydon[21])	19.6	0.7	29.7	50.0	0.449	0.543	0.007	74.6	0	0

4) Duffy System:

In this system 89.2% Duffy (Fy^a) positive bloods were found. A previous report of 100% Duffy (Fy^a) positive reactions[20] (in 30 specimens that had been stored for 16 months) indicates a need for verification and clarification.

5) Other Systems:

Kell tests were 100% negative as previously reported. Diego* tests were 100% negative.

The failure to demonstrate the Diego factor in any of the studies conducted in this area of the world is noteworthy. To date its absence in Polynesians,[21] Maoris,[22] and now in Marshallese becomes a significant finding in view of its occurrence in Mongoloids, Eskimos, and Amerindians,[23-25] to whom Heyerdahl[26] credits the population of the Polynesian Islands.

The gene frequency comparisons with other reports from this area are shown in Table 8.

The above findings indicate a rather homogenous population of the Marshall Islands with extremes of gene frequencies. With some reservations because of the relatively small samplings, the following facts are of interest in the blood groupings of the Marshallese.

1) The extremely high frequency of the O gene (78.9%).
2) The extremely low frequency of the M gene (14%).
3) The highest incidence of the R^1 chromosome yet reported (98.5%).
4) The presence of 10.8% of Duffy (Fy^a) negatives.
5) The absolute absence of Kell and Diego factors.
6) A single example of A_2B in this area.

The investigations of numerous authors, compiled and summarized by Mourant,[18] most nearly relate these blood groupings to those found in Southeast Asia and Indonesia, where relatively frequent B genes are found, a high N frequency exists, and a similar high frequency of the R^1 chromosome is seen.

The absolute absence of the Diego factor, the extremely low incidence of the M gene, and the unusually high R^1 chromosome frequency of the

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city of vital statistics in the Marshallese and the small numbers of people involved.

No diseases, infectious or noninfectious, have developed which could be related directly to radiation effects. The incidence of diseases in the exposed people noted during the 4-year survey, as in previous surveys, remained about the same as found in the unexposed comparison population. A limited survey of immune responses of the exposed group at 3 years post-exposure[5] showed that the antibody response to tetanus antigenic stimulus was not significantly different from the response in the unexposed group.

Three deaths have occurred in the exposed people. The first was in a 46-yr-old man who died of hypertensive heart disease 1 year post-exposure. He had had the disease at the time of irradiation. The second occurred in a 78-yr-old man at 2 years post-exposure. He was a diabetic of long standing and died apparently of coronary heart disease. A third occurred in April 1958, after the present survey, in a 35-yr-old man from the group that received 69 r, due to pneumonia complicating a severe case of chickenpox. In none of these cases was there any direct evidence that death was due to radiation exposure.

Lag in recovery of some of the peripheral blood elements of the exposed people over the 4-year period since exposure is in sharp contrast to the much more rapid recovery seen in animal studies, but generally conforms to the recovery pattern seen in the Japanese exposed at Hiroshima and Nagasaki. In the Marshallese the myelocytic series showed earliest recovery (by 1 year post-exposure), with lymphocytes and platelets exhibiting much slower recovery. The present hematological examinations reveal that the mean leukocyte level has virtually recovered to the control level, but more individuals had lower counts than in the unexposed group. Thrombocyte production still does not appear to have recovered completely as evidenced by the lower mean levels in the exposed people both individually and as a group. As has been pointed out, however, the slightly lower peripheral blood level of these elements has not impaired in any observable way their resistance to disease.

There has been considerable speculation as to whether there is a lowered reserve hemopoietic capacity in the marrow of the exposed people. The effect of the natural stresses of childbearing and menstruation in women 15 to 45 years of age was examined by comparing differences between the mean peripheral blood element levels of this group and the corresponding group of unexposed women with differences between levels in exposed and unexposed men of the same age group. No significant differences were seen.

It might be questioned whether or not the present low body burden of radionuclides might contribute to delayed recovery of hemopoietic function. Admittedly little is known of possible effects of such low level exposure on the marrow, particularly if, as in the case of the Marshallese, a significant dose of penetrating radiation has been previously received. However, it is not believed that the small amount of additional radiation imposed on the marrow from this source would be sufficient to retard hemopoietic recovery.

Hematological examination at 3 years post-exposure revealed a drop in the mean leukocyte counts compared with 2-year levels in both the exposed and unexposed people. The possibility was considered that a population trend downward in leukocyte counts was occurring such as has been seen in Japan.[47] However, this does not seem to be the case, since leukocyte levels this year are not further depressed compared with previous levels.

The acute effects of the beta irradiation of the skin subsided rapidly, and only 12 cases still show residual scarring and pigment abberation. It is possible that the acute stage of the beta burns may have caused some of the fluctuation observed in the white blood cell count. In those showing epilation, complete regrowth of hair occurred by 6 months post-exposure.

No acute effects of the internal absorption of radionuclides were observed.

LATE EFFECTS

Late effects of radiation exposure have not been seen, but certain of the more fundamental of these effects that have been observed in animals and to a lesser extent in man will be mentioned in relation to the Marshallese.

Shortening of life span[48–52] has not been evident. The 3 deaths that have occurred in the exposed population do not appear to indicate a higher mortality rate than seen in the comparison populations. From these observations it would appear that some of the higher estimates of life shortening per roentgen may be too high.

Premature aging[48,53] is difficult to assess. From observations over the past 4 years the impression is that exposed people neither have aged faster nor appear older than similarly aged unexposed Marshallese. No doubt the subtle changes which occur with aging would be difficult to detect over this period of time. During the 4-year survey, data were collected in an attempt to obtain semiquantitative estimates of biological age by scoring the degree of certain criteria such as greying of the hair, skin looseness, skin retractility, arcus senilis, retinal arteriosclerosis, accommodation, blood pressure, etc. These data have not yet been completely analyzed.

Degenerative diseases[54-56] have not been found to be increased in the exposed people. No ***malignancies*** have been detected. In the irradiated Japanese an increased incidence of leukemia has been noted.[57-59] There have been no cases of ***leukemia*** or ***leukemia tendency*** noted in the Marshallese. (No cases have shown decrease in alkaline phosphatase of neutrophils, nor have increased levels of basophils been noted.) Since the incidence of malignancy or leukemia would be expected to be relatively low with the dose of irradiation received, and since such a small population is involved, the probabilities are good that such effects will not be observed in the Marshallese.

Ophthalmological changes related to late effects of radiation[13-15] have not been seen. Slit-lamp observations over the past 4 years have revealed no polychromatic plaques or cataracts. No differences were found in visual acuity in the exposed and unexposed children.

Genetic effects.[60,61] No specific studies for genetic effects have been conducted. Of the 18 babies born to irradiated parents and living at the time of examination, none showed any abnormalities. In view of the generally negative findings in the studies of the first-generation offspring of the irradiated Japanese,[62] it is unlikely that genetic studies in this group will be fruitful.

Beta irradiation. No late effects of beta irradiation of the skin such as chronic dermatitis or premalignant changes have been found in the Marshallese.

FINDINGS COMMON TO BOTH EXPOSED AND UNEXPOSED GROUPS

Certain findings common to both exposed and unexposed Rongelap people may have possible significance in relation to their state of health and future prognosis. Clinical laboratory examinations have revealed a complexity of findings difficult to evaluate. Principal among these is the anemic tendency in the population at large. Hematocrit values of 38% or less were found in 54% of the men, and of 36% or less in 78% of the women. Also possibly related to this finding was the increase in reticulocyte counts (>3%) in about 20% of the people noted during the 3-year examination. The following have been considered as possible etiological factors:

1) Nutritional deficiency, such as low dietary proteins or iron deficiency. Although the diet is extremely limited and fish supplemented by small amounts of other meats are about the only source of proteins, there is no good evidence that such a deficiency exists. In fact the blood proteins are high (average 7.8 g%). It is not known whether the diet is deficient in iron. Blood smear examinations did not reveal any obvious microcytosis of red cells. The nature of the anemic tendency will be further investigated in the next survey by carrying out serum iron determinations and running Price-Jones curves of the red blood cells. Poor absorption or deficiency of vitamin B_{12} is apparently not a factor since the levels of B_{12} in the serum were surprisingly high. (Experience with *Diphyllobothrium latum* infestation suggests that parasitism of the gastrointestinal tract should be associated with low vitamin B_{12} serum concentrations.) The relatively high values of serum vitamin B_{12} are puzzling, and no immediate explanation is apparent.

2) Intestinal parasitism is very prevalent, 72% of the people showing stools positive for ova and parasites. However, examination of these stools for occult blood showed positive tests in only 10 people. Chronic blood loss from this source does not seem likely; also, anemia is not usually associated with the parasites found in these people.

3) Chronic infections, particularly skin diseases and dental caries, may play an etiological role in the production of the anemic tendency. The high plasma protein levels with high gamma globulin component may be a reflection of such infectious processes.

The presence of eosinophilia in the population is another puzzling problem. (About half the people show eosinophils >5% in their differential counts with quite a few values as high as 20 and 25%.) Offhand, it might seem that the high incidence of intestinal parasites might account for the high eosinophil counts. However, as pointed out, most of the types of parasites found are not usually associated with a consistent eosinophilia, and indeed a large group of individuals with high eosinophil counts had stools negative for parasites. However, the greater incidence of eosinophilia among Marshallese with stools positive for *T. trichiura* indicates that infection with this helminth may be a contributing factor, but this does not entirely explain the generally high incidence noted. Possibly chronic infections, particularly fungus infections of the skin, may be partly responsible. Another possibility is trichinosis infestation, which has to be considered seriously in view of the large number of rats on the island and the presence of swine (used to a small extent for meat) roaming freely. On the next survey serological tests for trichinosis antigen will be carried out.

An unexpected finding was that the level of serum protein-bound iodine in these people was significantly above the normal range. Butanol-extractable iodines on 6 cases also showed values at the upper limit of normal, but thyroxine-binding capacity determinations on 12 cases gave data inadequate to define precisely whether the slight elevations were significantly different from normal. However, it could be calculated that the level of thyroxine-binding protein was insufficient to cause the elevation of serum thyroxine (presumably to maintain a normal level of free thyroxine) noted in these people.

The study of genetically determined traits has proved most interesting in helping to establish the anthropological background of the Marshallese people and the homogeneity of the population under study. Interesting findings in the studies of blood groupings were the high frequency of the O gene (78.9%), the extremely low frequency of the M gene (14%), the highest incidence yet reported of the R′ chromosome (98.5%), the presence of 10.8% of Duffy (Fy^a) negatives, the absence of Kell and Diego factors, and a single sample of the A_2B group. These groupings most closely resemble those of the people of Southeast Asia and Indonesia. Haptoglobin studies showed a very high incidence of the $1-1$ type and the Hp′ gene exceeded only by that of the Yorubas of Nigeria. No unusual hemoglobin types were noted. These findings suggest a rather homogenous population.

RADIATION ECOLOGICAL STUDIES

It seems appropriate to discuss the Marshall Island data as part of the world-wide fallout problem. There has been much concern expressed both in scientific journals and in popular articles about the hazard from fallout, particularly Sr^{90}. The general situation as of mid-1957 has been reviewed by Robertson and Cohn,[63] with the conclusion that existing levels of radiation from fallout add little to the environmental radiation hazard. Eisenbud and Harley[64] present data indicating that in the United States Sr^{90} continues (in 1958) to be deposited at a rate of 11 to 54 mC/mi^2. The average for the rest of the Northern Hemisphere is 16 mC/mi^2, which is about twice the value for the Southern Hemisphere. Kulp and Slakter[65] conclude that the diet of an average U.S. citizen in 1957 contained about 6.5 $\mu\mu$C Sr^{90}/g calcium, which corresponds to an equilibrium base level of 1.6 $\mu\mu$C/g if the discrimination factor between diet and bone is 4. Finkel,[66] in an appraisal of the potential Sr^{90} danger based on data from animal experiments, concludes that the minimum effective dose in man may be a burden of from 5 to 10 μC Sr^{90}, in close agreement with an estimate of 6 to 15 μC based on the radium method of extrapolation. Hindmarsh et al.[67] have re-evaluated the relative hazards of Sr^{90} and Ra^{226}. Their conclusion is that the currently accepted maximal permissible dose figures for Sr^{90} are substantially correct. Brues[68] reviews the arguments upon which is based the fear that very low doses of Sr^{90} might produce a "very low (but in absolute numbers appreciable) incidence of leukemia" and concludes that the present data fail to indicate a linear relationship for dose and effect at low doses. He further emphasizes the fact that there are other theories of the etiology of cancer, and that their existence weakens the arguments of those who would assign unrealistically high probabilities to the role of single mutations as being the cause of cancer.

Gilliam and Walter[69] have studied the trends in the mortality from leukemia. In most age groups the death rate has been increasing exponentially since 1921, with doubling times of about 15 to 20 years for most age groups. The younger age groups, however, have recently shown a tendency to level off, or, in the authors' words, since 1940 there has been "a distinct tendency toward a decline in the rate of increase." This tendency is more definite with decreasing age, and in the age group 0 to 1 year there has been an actual decline in the death rate from leukemia. If leukemia follows from exposure to an environmental factor, the mortality data suggest that exposure of the population to this factor has decreased recently.

Schwartz and Upton[70] have considered the role of ionizing radiation in the general incidence of leukemia and lymphomas. Among other factors considered are age, race, sex, geographical location, climate, genetic factors, constitutional factors, and other extrinsic agents such as chemicals and infectious agents. These authors consider the increase in radiation background from all causes (medical, dental, fallout, etc.) to be "clearly not sufficient to account for the tremendous rise in the recorded incidence of leukemia. . ." Burnet[71] points out that the present peak of incidence of leukemia at age 3 to 4 is a relatively recent development and suggests the possibility that exposure to some new mutagenic agent at the time of birth is the cause. He cites data which indicate that at most 5 to 10% of leukemia incidence in the United States can be ascribed to radiation from all sources, and points out that the etiology of the other 90% is unknown.

Other constituents of fallout have not received as much publicity as Sr^{90}, but their study has not been neglected.[72-78] Anderson[72] reports an extensive series correlating Cs^{137} and K^{40} levels in people and in milk supplies. He states that the importance of Cs^{137} relative to Sr^{90} is increasing. The levels in both people and milk representing various locales in the United States ranged up to 60 $\mu\mu C$ Cs^{137}/g K, with fairly good correlation between the two levels. These results are consistent with those reported by Miller and Marinelli,[78] who have further data suggesting a rather uniform distribution of fallout in the Northern Hemisphere.

The significance of low doses of radiation has not been evaluated fully, the chief reason being the absence of positive data on low-dose effects, particularly in humans. Perhaps more subtle methods will be found by means of which low-dose effects can be documented, but it is to be hoped that the radiation dose can be maintained below the level at which effects appear with any method.

In the meantime, the Rongelap people provide an interesting group of subjects exposed to a level of radiation appreciably above the world average. Present indications are that the body burdens of radionuclides will not reach levels which, from known data, will result in morbid processes. As pointed out before, the development of leukemia associated with their exposure to a sublethal dose of gamma radiation in March 1954, based on experiences with the exposed Japanese,[57-59] is held to be improbable, particularly in view of the small number of people involved. The superimposition of the low level body burdens from environmental contamination would not seem likely to be sufficient to increase this possibility substantially.

The habitation of these people on Rongelap Island affords the opportunity for a most valuable ecological radiation study on human beings. Since only small amounts of radioisotopes are necessary for tracer studies, the various radionuclides present on the island can be traced from the soil through the food and into the human being, where the tissue and organ distributions, biological half-times, and excretion rates can be studied.

Summary

The medical survey of the Rongelap people in March 1958, 4 years after exposure to accidental fallout radiation, was carried out at Rongelap Island, to which these people had been returned in July 1957 after the radiation level of the island was declared safe for habitation. They were adjusting satisfactorily to life in their newly reconstructed village.

No apparent acute or subacute effects were found at this time related to the gamma dose of 175 r received, with the possible exception of hemopoietic findings indicating a persisting lag in complete recovery of platelet levels of the peripheral blood. In the males these mean levels were 11 to 16% and in the females 9% below the corresponding mean levels of the comparison population. The lymphocytes had recovered to a level about the same as in the comparison population, although many of these counts were lower than in the latter group. The stress of childbearing and menstruation did not appear to be reflected in any lowered hemopoietic reserve in the exposed women, based on comparative studies of the levels of peripheral blood elements. The suggestive incidence, previously reported, of slight lag in growth and development of the irradiated children at 2 and 3 years after exposure, based on height, weight, and bone age studies, needs re-evaluation in the light of the finding that the ages of some of the children were not as firmly established as previously thought. History and physical examinations revealed no clinical evidence of any illnesses or findings during the past year or at the time of the present survey which could be related to whole-body exposure.

Two deaths occurred in the exposed and one in the unexposed group since the last survey. The deaths in the exposed group did not appear to be related to radiation exposure. Diseases, infectious and noninfectious, were as common in the exposed as in the unexposed people. Nutrition appeared good except for slight hemeralopia in several children ascribed to vitamin A deficiency. The birth rate was about the same in the exposed as in the unexposed group, and the babies appeared normal.

No late effects of exposure were noted. Shortening of life span has not been observed. The death rate has been about the same in the exposed as in the unexposed population. Premature aging of the irradiated group has not been grossly visible. No radiation opacities of the lens or differences in visual acuity have been noted. No malignancies have been observed, and the incidence of degenerative diseases was about the same as in the unexposed group examined. Genetic studies have not been carried out, but no difference in the incidence of congenital abnormalities has been noted in the first-generation children of the exposed compared with the unexposed populations.

The only residual effects of beta irradiation of the skin were seen in 12 cases which showed varying degrees of pigment abberation, scarring, and atrophy at the site of deeper burns. In no case was there evidence of chronic radiation dermatitis or premalignant or malignant change in the lesions.

The return of the Rongelapese to their island (which has a persisting low level of radioactive contamination) is reflected in a rise in their body burdens and increased urinary excretion of certain radionuclides. Estimates of these body burdens of radionuclides were determined by gamma spectroscopy and by radiochemical analyses of urine samples. These estimates showed that the body burden of Cs^{137} had increased by a factor of 100 and of Sr^{90} by a factor of 10, with some increase in Zn^{65} also, since the return to Rongelap. However, the levels were well below the accepted maximum permissible levels. Analysis of bone samples on one of the men who died showed 3.7 Sr^{90} units/g calcium. Further detailed studies on the radiation ecological aspects of these surveys, including examinations of the food and human metabolism of these isotopes, is in progress and will be an important part of future investigations.

The survey team devoted considerable attention to other medical studies in the Marshallese not directly related to radiation effects but possibly having some bearing on prognosis. Findings in these studies were common to both the exposed and unexposed populations. An extensive intestinal parasite survey showed that the people were infected with many types of protozoa and helminths, although this finding did not entirely account for the generally higher incidence of eosinophilia. Among other findings that need further explanation are the general anemic tendency, the high plasma protein levels with increased gamma globulin, and the high levels of serum protein-bound iodines and vitamin B_{12}. It is hoped that some of these problems will be solved in future surveys.

Another group of investigations concerned the anthropological background of the Marshallese based on studies of genetically determined traits. Among these were determinations of various blood groups and of hemoglobin and haptoglobin types. These studies are shedding some light on the origin of these people and on the homogeneity of the population being investigated. Their blood groups resemble most closely those of people from Southeast Asia and Indonesia, and the population appears to be relatively homogenous.

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